Characterization of Water Jets for Safe Removal of Explosive Fillings

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ABSTRACT

This paper reports the characterisation of water jets to be used for washing out the filling of explosive ordnance. Water jets have advantages over conventional techniques in that they are non-polluting and can effectively disperse all compositions; pressed, cast, plastic and PBX.

The water jets studied are produced by a gas gun consisting of a parallel barrel and a detachable tapered nozzle. Four nozzle designs were tested with exit-diameters ranging from 27 mm to 16 mm. A plastic piston regulates the volume of the water charge. For various combinations of water volume, breech pressure and nozzle diameter, high speed cine photography and flash radiography was used to characterise the water jets in terms of velocity and coherence. Water jets were achieved with jet-tip velocities between 100 and 600 m/s and breech pressures in the range of 30-100 MPa.

The water jets have been fired at plastic explosive compositions and dispersed the explosive with little chance of initiating a reaction, even when heavily confined. The water jet is capable of penetrating moderate thicknesses of sheet metal so could be used where the explosive filling is directly accessible or thinly covered eg. fuse-well. Continuous water jets with similar characteristics could be used for demolition of unfused ordnance, eg. depot demolition, or following an EOD operation where the fuse(s) has been removed by some other technique.

1. Introduction

Water jets have several advantages over conventional methods of washing out the filling of explosive ordnance. Incineration, slow burning or detonation all present environmental problems and steam only works for melt-cast compositions whereas water jets are non-polluting and can disperse all compositions; pressed, cast, plastic and PBX.

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Ultra high velocity, abrasive water jets are widely used to cut various materials and several studies have been done on the interaction of these jets with explosive compositions [1 & 2]. These water jets typically have diameters of a few millimetres and velocities of several kilometres per second. Lower velocity (several hundred metres per second) water jets offer an alternative which would be cheaper to operate and maintain due to the lower pressures used.

This report characterises water jets produced by a simple gas gun and investigates the interaction of these water jets with common explosive compositions.

2. EXPERIMENTAL

2.1 Equipment

Water jets were produced with a range of characteristics by a gas gun consisting of a parallel barrel, piston and a removable nozzle. The water jet parameters can be altered by changing the gas pressure, the water load and the nozzle. Four nozzle designs have been tested; one parallel and three which taper to 23, 19 and 16 mm respectively. The length of the nozzle remained constant in each case. The normal method of loading the water into the device was to insert the piston to a predetermined depth and then pour water in until it was flush with the end of the nozzle, which was then sealed. Three tests were conducted with the water contained within the parallel section of the barrel, ie. the nozzle empty.

2.2 Characterisation of Water Jets

High speed cine (HSC) photography and flash x-ray (FXR) imaging have been the primary diagnostic tools for characterising the water jets. HSC provides a continuous record of an event with many images which is important for accurate velocity data. FXR in contrast, provides only 1 or 2 images but the x-rays are able to penetrate the spray dome to reveal the detailed structure.

2.2.1 High Speed Cine Photography

A Hycam HSC camera was used for all test firings. It was fitted with either a full frame or quarter frame optical head depending on the framing rate and image format required. The quarter frame optical head splits each normal 16 mm frame into four, with each quarter frame correspondingly advanced in time. The effective "framing" rate is effectively four times that available with a full frame optical head at the expense of frame height. In all cases the camera was set to run at full speed which gave a framing rate of just over 7500 and 30000 frames/s for the full frame and quarter frame firings respectively.

Diffuse back illumination of the water jet was achieved using a custom made light source consisting of up to six Sylvania No. 2 flashbulbs. A sheet of perspex, with tracing paper taped to it, was positioned about 300 mm in front of the flash bulbs and a sheet of Roscomat diffusing material was positioned half way between the perspex and the flash bulbs.

Appropriate scaling and reference marks were attached to the perspex sheet.

The films were analysed on a Vanguard Instruments Corporation motion analyser by positioning the cross-hairs on the leading edge of the advancing jet. The horizontal co-ordinate of this point was then recorded for each frame. A magnification factor was calculated from the physical layout of the system and then used in conjunction with calibration lines on the film to determine the displacement data for each firing.

The framing rate was calculated for each film in the normal manner using timing marks automatically placed on the film by the camera. The time data was calculated simply by incrementing the time for each frame by the appropriate amount. Time t=0 is when the jet first emerges from the nozzle.

The displacement data was plotted against time and then numerically differentiated by the parabolic least squares technique based on three points either side of the point being evaluated. The resultant velocity-time curve was then combined with the original displacement-time curve to finally end up with velocity versus displacement.

In order to plot velocity against breech pressure we required velocity values at specific displacements. This was achieved by fitting a second order polynomial to the appropriate velocity-displacement curves and reading the values at a nominally chosen jet tip displacements.

2.2.2 Flash Radiography

The FXR system consists of four Fexitron 300 kV pulsers, all equipped with remote heads. Emergence of the water jet from the nozzle was detected by a helium-neon laser and a custom made detector aligned perpendicular, and as close as practical, to the end of the nozzle. The purpose of the laser was to achieve a reliable time zero when the water emerged from the nozzle without interfering with the jet. The detector triggered a multi-channel delay pulse generator (DPG) which in turn fired the x-ray pulsers. Two orthogonally positioned tube heads delivering 185 kV soft X-rays were used for these firings (ie. two images per test). Images were obtained on Kodak X-OMAT RP film.

A magnification factor for each film position was calculated from the geometry of the set-up. Displacements of the jet-tip, length of the jet and diameter of the plume were then measured and adjusted accordingly.

2.3 Explosive Sensitivity to Water Jet Impact

In order to assess the sensitivity of explosive compositions to water jet impact, water jets of various parameters were fired at several bare explosive compositions. In this preliminary study, readily available explosives with a wide variation in sensitivity were chosen. Powergel, Metabel and Gelignite AN60 are all commercial plastic explosives and although they are not typical of military ordnance fillings, they will indicate whether any reaction is likely. That is, if there is no reaction from these more sensitive compositions then there is unlikely to be a reaction from less sensitive ordnance fillings.

For all tests, the explosive samples were placed 75 mm from the nozzle on a 10 mm thick mild steel witness plate. Initially the sample was bare, ie. unconfined, but if no reaction was achieved from any of the water jets, a 28 mm diameter steel pipe was welded to a witness plate and hand filled with the explosive sample. The water jet was then fired into the open end of the cylinder. The heavy confinement greatly increases the chance of initiating and maintaining a reaction from the explosive. The use of witness plates in this manner is an easy and reliable method of determining the type of reaction by examining the profile of the dent in the plate. A detonation produces a sharp dent whereas a deflagration only dishes the plate.

3.0 RESULTS AND DISCUSSION

3.1 Characterisation

The HSC photography reveals very little detailed structure of the jet as the image is a shadowgraph but despite its shortfalls, the HSC is invaluable when it comes to quantitative data due to the comparatively large number of data points. FXR, by contrast, reveals the detailed inner structure of the jet. Figure 1 is a compilation of six independent tests with the same parameters. A close look at the images reveals that the structure of the jet is reproducible from one firing to another even down to the pulses in the column and the fine structure of the plume. This indicates that the functioning of the equipment is consistent and reproducible from one firing to the next. Figure 2 is an illustration of the fourth image from Figure 1, highlighting the important characteristics of the water jet.

Figure 1: Sequence of flash x-ray images of a typical water jet.

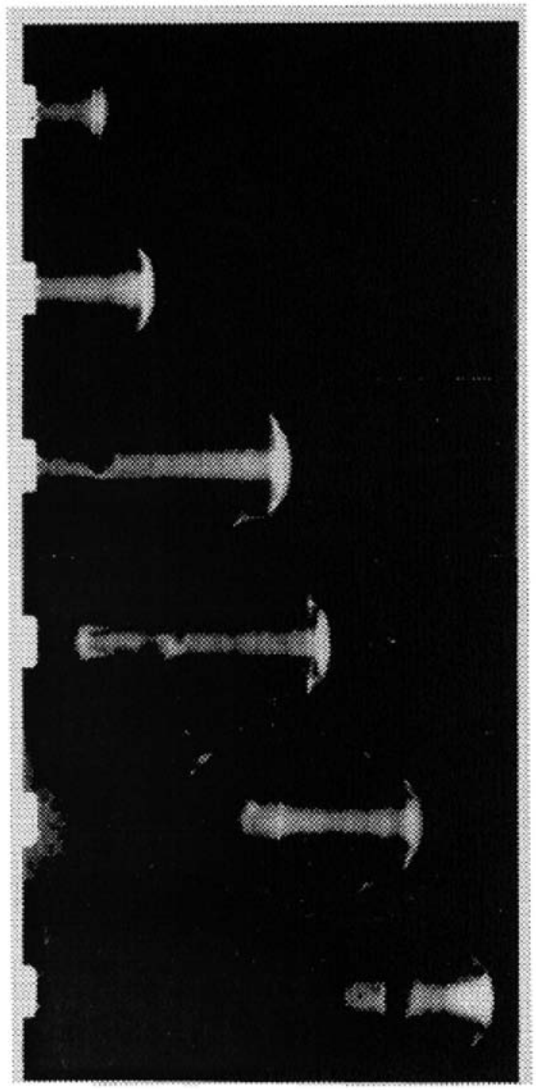

Figure 1: Sequence of flash x-ray images of a typical water jet.

Figure 2: Illustration of a flash x-ray image from Figure 1.

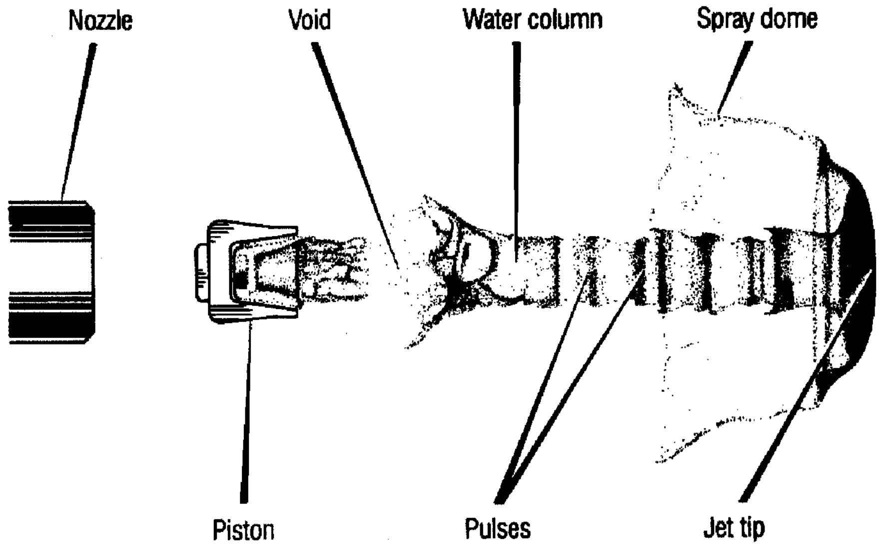

Figure 2: Illustration of a flash x-ray image from Figure 1.

If the breech pressure is increased the velocity of the water jet would be expected to increase accordingly. Figure 3 illustrates the relationship between breech pressure and jet-tip velocity which clearly shows the expected result. The velocities are measured at 200 mm from the nozzle.

Figure 3: Plot of breech pressure vs jet-tip velocity measured at 200 mm from the nozzle.

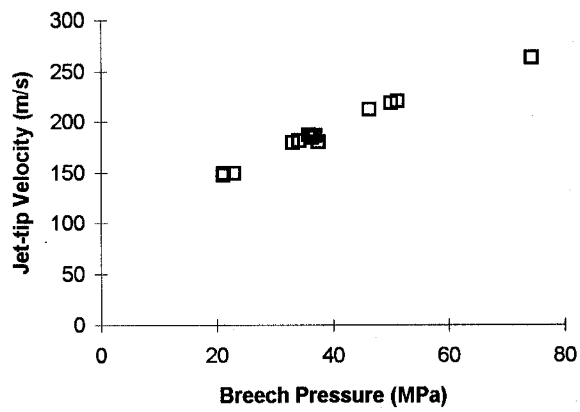

Figure 3: Plot of breech pressure vs jet-tip velocity measured at 200 mm from the nozzle.

The maximum velocity (at 200 mm from the nozzle) that can be achieved with the normal loading procedure (ie. nozzle full) is about 300 m/s. Higher velocities are possible if the water load is initially positioned completely within the parallel section of the barrel by sealing the barrel prior to installing the nozzle. With a breech pressure of around 55 MPa, the velocity for this configuration varied from about 400-600 m/s (cf. Figure 3). The structure of the jet was unlike any of the others in that the front was very turbulent with no clearly defined air/water interface.

To understand why the velocity should be so different between the two configurations, consider the following expression derived from the mass flow rate of an incompressible, non-viscous fluid flowing through a constriction in a pipe:

$$v^1A^1 = v^2A^2$$

where

v^1 = initial velocity
A^1 = initial cross-sectional area
v^2 = final velocity
A^2 = final cross-sectional area

If we consider the jet as a number of discrete segments, the final velocity of each segment (exit velocity from the nozzle) is proportional to the initial velocity that that segment has on entering the constriction and the ratio of the cross-sectional area of the pipe before and after the constriction.

Each discrete segment of water therefore enters the nozzle with a greater velocity and also travels a greater distance through the nozzle therefore experiencing a greater reduction in cross-sectional area. So both the initial velocity and the ratio of cross-sectional areas are greater, resulting in an increase in exit velocity of the water jet.

3.2 Explosive Sensitivity to Water Jet Impact

It is unknown at this stage, what mechanism is responsible for initiating a reaction at the relatively low velocities produced of these water jets so a number of different water jets were tested. None of the unconfined compositions reacted at all to any of the water jets and even when heavily confined, only the highest velocity water jet that the gas gun can produce initiated a reaction and then only in the Gelignite AN60 (Table 1).

All of the water jets were very effective at dispersing the explosive. In the tests where the explosive was pressed into the 28 mm diameter steel pipe, it was completely ejected from the pipe. Other tests have demonstrated that the water jet can easily break up and disperse plaster so if would be just as effective against cast compositions such as Composition B (F of I: 150).

Table 1: Summary of explosive compositions tested.

				Results	
Explosive	**Energetic constituents**	**VoD (m/s)**	**F of I**	**Conf**	**Unconf**
Gelignite AN60	60% Ammonium Nitrate 27% Nitroglycerine	2000 - 3000	36 - sample A 57 - sample B	Def	NR
Metabel	70% PETN (+ DNT & TNT)	7300	125	NR	NR
Powergel	Ammonium Nitrate	5600	>165	NR	NR

Def → deflagration
NR → no reaction

Table 1: Summary of explosive compositions tested.

These water jets will not penetrate the case of munitions as the velocity is too low to erode metal. So for this technique to be used, the filling of the munition has to be exposed by removing the fuse or cutting the case open with some other technique. Even after the fuse has been removed, the explosive may not be directly accessible due to the presence of a booster can. This will not present a problem as tests have demonstrated that the water jet is capable of penetrating thin metal sheets.

4. Conclusions

The water jet produced by a simple gas gun has been characterised and the interaction of the water jet with explosive compositions has been investigated as a feasibility study for using high velocity, large diameter water jets to wash out the explosive filling of ordnance in an environmetally friendly way. A summary of our findings are:

1. Both Flash x-ray (FXR) imaging and high speed cine (HSC) photography have been used to characterise the water jets. By altering the various parameters, velocities of up to 600 m/s are possible with this simple gas gun.

2. The tests indicate that there is little chance of initiating common secondary explosive compositions with these low velocity, large diameter water jets. Of the explosives tested, only Gelignite AN60, an NG-based composition, was initiated and then only when heavily confined.

3. The water jet easily dispersed the explosive samples. In tests where the sample was filled into a 28 mm diameter steel tube, closed at one end, the sample was completely ejected from the tube.

4. The velocity of these water jets is not high enough to penetrate the case of explosive ordnance, so must have direct access to the explosive or at most, a thin barrier (eg. booster can) covering the explosive.

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6. References

1. Worsey, P.N., Summers, D.A. and Craig, L.E. Waterjet Impact Sensitivity Test Manual Ordnance Engineering Department, Naval Weapons Support Centre, Crane, Indiana.

2. Giltner, S.G., Sitton, O.C. and Center, P.N. Detonation and Reaction of Class 1.1 Explosives and Propellants Due to Water Jet Impact. The Tenth International Detonation Symposium, 1993.